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RED BLOOD CELL VOLUME, PLASMA VOLUME AND TOTAL BLOOD VOLUME IN HEALTHY ELDERLY MEN AND WOMEN AGED 64 TO 100

BY

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In healthy men and women aged 64 to 100 years of age, red blood cell volume was measured using ^{51}Cr-labeled fresh autologous red blood cells, and plasma volume was measured using ^{125}I albumin. These measurements were correlated to budy surface area (BSA) and body weight (BW).

In these elderly healthy male and female subjects, red cell volumes were 11 to 23% lower than, plasma volumes were similar to, and total blood volumes were slightly lower than values previously reported in younger subjects. The

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red blood cell volume showed no correlation with the peripheral venous hematocrit or the red blood cell 2,3 DPG, ATP, or P50.

ABSTRACT: In healthy men and women aged 64 to 100 years of age, red blood cell volume was measured using ^{51}Cr- labeled fresh autologous red blood cells, and plasma volume was measured using ^{125}I albumin. These measurements were correlated to body surface area (BSA) and body weight (BW).

In these elderly healthy male and female subjects, red cell volumes were 11 to 23% lower than, plasma volumes were similar to, and total blood volumes were slightly lower than values previously reported in younger subjects. The red blood cell volume showed no correlation with the peripheral venous hematocrit or the red blood cell 2,3 DPG, ATP, or p50.

We report the red blood cell, plasma and total blood volumes in relation to body surface area (BSA) and body weight (BW), and report regression equations used to estimate red blood cell, plasma and total blood volumes.

INTRODUCTION: Our study of healthy men and women 64 to 100 years of age was done to determine whether individuals in this age group have blood volume measurements that are different from those of younger individuals[1-10]. We used ^{51}Cr-labeled autologus red cells to measure red blood cell volume, and ^{125}I albumin to measure plasma volume. We also measured red blood cell ATP, DPG, and p50 levels.

METHODS: The 51 healthy elderly volunteers (32 females and 19 males) who participated in the study signed informed consent forms in accordance with the Institutional Review Board for Human Research at Boston University Medical

Center. Participants were interviewed and were medically examined to determine their health status and use of medications. Each subject was screened for cardiovascular, renal, liver, and metabolic diseases. All participants were physically active and in good health.

The subjects were maintained in a supine position for 30 minutes prior to infusion of the ^{51}Cr-labeled red blood cells and the ^{125}I albumin. To measure red blood cell volume, a 20 milliliter (ml) blood sample was collected, incubated at 37 degrees Centigrade for 30 minutes with 11.5 microcuries of ^{51}Cr disodium chromate (ER Squibb & Sons). A 10 ml volume of ^{51}Cr-labeled fresh autologous red blood cells containing 5 microcuries was reinfused. To measure plasma volume, a solution of 1.5 microcuries of ^{125}I human albumin in isotonic saline was prepared, and a 5 ml volume of the solution containing 0.5 microcuries was infused.

Venous blood samples were obtained before infusion and 20 and 30 minutes after infusion for measurements of radioactivity in the blood and plasma. Red blood cell volume (RCV) was calculated from the total ^{51}Cr radioactivity associated with the injected red blood cells and ^{51}Cr radioactivity associated with the red blood cells 20 and 30 minutes after infusion. Plasma volume (PV) was calculated from the total injected ^{125}I radioactivity and the mean plasma ^{125}I radioactivity 20 and 30 minutes following infusion. The total blood volume was calculated as the sum of the ^{51}Cr red blood cell volume and the ^{125}I albumin plasma volume.

The peripheral venous microhematocrit was measured before and after the infusions of the ^{51}Cr labeled red blood cells and the ^{125}I albumin. The total body hematocrit was calculated from the red cell volume divided by the total blood volume, RCV / (RCV+PV), and the f-value was calculated from the total body hematocrit and the peripheral venous hematocrit [11,12,13].

At the time that the red blood cell and plasma volumes were being measured, peripheral venous blood was collected to measure red blood cell 2,3 DPG, ATP, and p50 levels. Red blood cell adenosine triphosphate (ATP) and 2,3 diphosphoglycerate (2,3 DPG) levels were measured fluorometrically[14,15]. The red blood cell p50 was measured in washed red blood cells in a phosphate buffer solution, pH 7.2 at a temperature of +37C and a pCO2 tension of 0 mm Hg (Hemoscan Oxygen Dissociation Analyzer, American Instruments Co., Silver Spring, MD)[16]. The pO2 tension at which 50 percent of the hemoglobin was saturated with oxygen is reported as the p50 value.

Statistical analyses were performed using Statistical Analysis Systems (SAS) licensed to Boston University, and included means, standard deviations, and linear regression and correlation.

RESULTS: Table 1 reports the age, height, body weight (BW), body surface area (BSA), and peripheral venous hematocrit of the 19 men and 32 women in the study. The mean age of the men was 73, with a range of 64 to 100; the mean age of the women was 74, with a range of 65 to 93. No significant correlation was seen between the age of the male and female subjects and their red blood cell, plasma, or total blood volume.

The mean ^{51}Cr red cell volume (RCV) for the men was 1662 ml, and when this measurement was related to body indices, the value was 889 ml/m^2 for body surface area (BSA) and 22.6 ml/kg for body weight (BW) (Table 2). The regression equation relating the red cell volume (ml) to body surface area (m^2) was RCV = $1761(m^2) - 1608$, and to weight (kg) was RCV = 25.1 (kg) - 183 (Table 3). The body surface area (BSA) accounted for 75% of the variance in red cell volume with a correlation coefficient of r=0.868, and the body weight (BW) accounted for 72% of the variance with a correlation coefficient of r=0.846 (Figures 1 and 2).

In the male subjets, mean plasma volume measured by ^{125}I albumin was 3029 ml, 1634 ml/m^2 BSA, and 41.9 ml/kg BW (Table 2). The regression equation relating the plasma volume to body surface area (BSA) was PV = $1995(m^2) - 667$, and to weight was PV = 24.3(kg) + 1255 (Table 3). The BSA accounted for 43% of the variance in plasma volume with a correlation coefficient of r=0.657, and the BW accounted for 30% of the variance with a correlation coefficient of r=0.549 (Figures 1 and 2).

The male subjects exhibited a mean total blood volume (TBV) of 4693 ml, 2626 ml/m^2 BSA and 64.6 ml/kg BW (Table 2). The regression equation relating the total blood volume to body surface area was TBV = 3809(m^2) -2362, and to weight was TBV = 49.9(kg) + 1044 (Table 3). The BSA accounted for 67% of the variance in blood volume with a correlation coefficient of r=0.818, and the BW accounted for 54% of the variance with a correlation coefficient of r=0.736 (Figures 1 and 2).

In the female subjects, the mean red cell volume was 1185 ml, and the red blood cell volume was 725 ml/m^2 BSA and 19.3 ml/kg BW (Table 2). The regression equation relating the red blood cell volume to body surface area was RCV = 716(m^2) + 14, and to weight was RCV = 9.7(kg) + 573, (Table 3). The BSA accounted for 46% of the variance in red cell volume with a correlation coefficient of r=0.681, and the BW accounted for 49% of the variance with a correlation coefficient of r=0.699 (Figures 3 and 4).

The mean ^{125}I albumin plasma volume in the female subjects was 2310 ml, 1424 ml/m^2 BSA and 38.3 ml/kg BW (Table 2). The regression equation relating the plasma volume to body surface area was PV = 925(m^2) + 802, and to weight was PV = 10.9(kg) + 1630 (Table 3). The BSA accounted for 30% of the variance in plasma volume with a correlation coefficient of r=0.553, and the BW accounted for 23% of the variance with a correlation coefficient of r=0.484 (Figures 3 and 4).

The female subjects exhibited a mean total blood volume of 3482 ml, 2144 ml/m^2, and 57.6 ml/kg (Table 2). The regression equation relating the blood volume to body surface area was TBV = 1591(m^2) + 889, and to weight was TBV = 19.9(kg) + 2247 (Table 3). The BSA accounted for 48% of the variance in blood volume with a correlation coefficient of $r=0.696$, and the BW accounted for 41% of the variance with a correlation coefficient of $r=0.642$ (Figures 3 and 4).

The mean f-value in the men was 0.88 with a range of 0.81 to 0.96, and in the women was 0.88 with a range of 0.77 to 1.05 (Table 2).

Table 4 reports the red blood cell volume, plasma volume and total blood volume data from previous studies and from our present study of elderly men and women. The red cell volumes related to body size indices were 11 to 23% lower in the elderly men and women in our study than in the younger subjects in previous studies[3,4,5,7,10]. The plasma volumes in our elderly subjects were within ± 5% those observed in the younger individuals in the previous studies, and blood volumes were 3 to 8% lower[5,7,10]. Data from other studies in subjects over the age of 60 showed plasma volumes within ± 5% of our values in one study[8] and in another study 12% lower than our values for men and 16% lower for women[9]. A third study reports red blood cell volumes 13% higher than our values[10].

In our study reported here, the age of the subjects did not correlate significantly with the red blood cell 2,3

DPG, ATP or p50 level (Figure 5). Nor was there any significant correlation between peripheral venous hematocrit in the elderly men and women and the red blood cell ATP, DPG, or p50 level (Figures 6, 7 and 8). The red blood cell volume in these subjects did not significantly correlate with red blood cell ATP, 2,3 DPG, or p50 level (Figures 9, 10, 11, 12, 13, and 14).

DISCUSSION: The purpose of our study was to measure red blood cell, plasma, and total blood volumes in healthy elderly men and women aged 64 to 100. We wanted to determine a nomogram from which to predict the red blood cell, plasma and total blood volumes from body surface area and body weight. Red blood cell, plasma and total blood volumes were found to correlate with both body surface area (BSA) and body weight (BW), a finding similar to that reported by other investigators who studied younger subjects [1-10]. In our study, the regression equations were slightly more accurate for body surface area (BSA) than for body weight (BW).

The elderly subjects in our study exhibited red blood cell volumes that were consistently lower than those measured in younger subjects using ^{51}Cr labeled red blood cells [3,4,5,7,10]. Plasma volumes were similar to those seen in younger men and women in other studies, and total blood volumes were slightly lower [5,7]. The reductions in red blood cell volume in our elderly subjects were not associated with either increases in plasma volume or decreases in peripheral venous hematocrit [12,13].

We did not measure lean body mass in our elderly subjects as a means of assessing the correlation between red blood cell volume and the lean body mass. However a study of younger subjects has shown that lean body mass correlated with red blood cell volume[3] and with red blood cell, plasma and total blood volumes[7].

Plasma volumes that were measured using ^{125}I albumin and related to the body surface area (BSA) were similar to values seen when T-1824 dye was used[8]. The plasma volumes related to body weight (BW) that were 12% to 16% higher in our study than those reported by Sklaroff[9] may have been due to the fact that our subjects were living at home and were physically active, whereas his subjects were residents in a home for the aged. The subjects in the study by Schmidt, et al[8] were custodial patients in a state hospital.

The normal 2,3 DPG levels and significant reductions in red blood cell volume in our subjects suggest an adaptive red blood cell volume deficiency[17]. The absence of an increase in red blood cell 2,3 DPG accompanied by a significant deficit in red blood cell volume suggests that these elderly patients had an adequate oxygen supply to the tissues. The deficiency in red blood cell volume in our elderly subjects was consistent with an adaptive and not a pathologic deficiency in red blood cell volume.

FIGURE 1

RELATIONS BETWEEN BODY SURFACE AREA (BSA) AND RED BLOOD CELL, PLASMA AND BLOOD VOLUMES IN ELDERLY MEN

RELATIONS BETWEEN BODY SURFACE AREA AND RED BLOOD CELL, PLASMA AND BLOOD VOLUMES

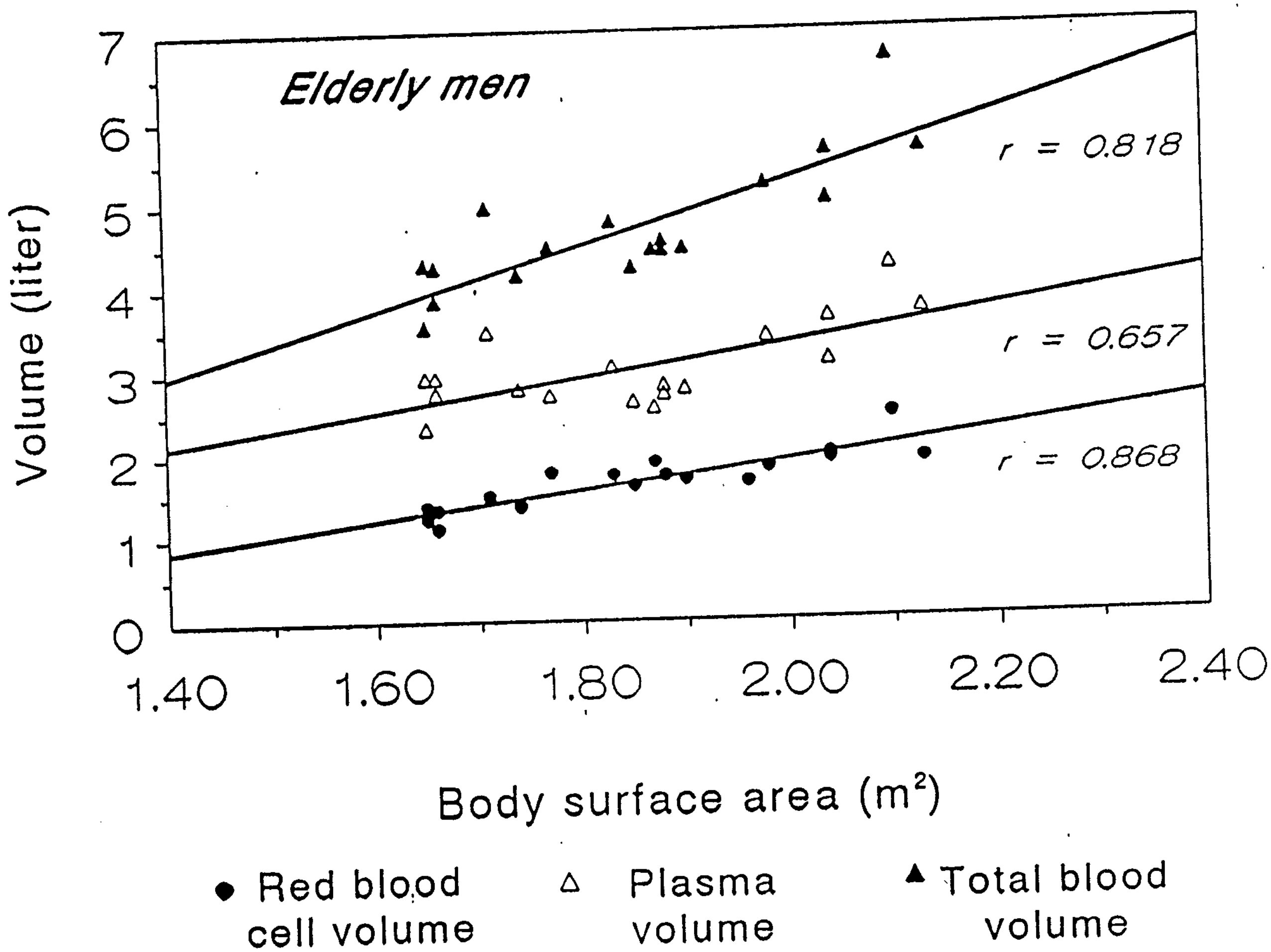

FIGURE 2

RELATIONS BETWEEN BODY WEIGHT (BW) AND RED BLOOD CELL, PLASMA AND BLOOD VOLUMES IN ELDERLY MEN

RELATIONS BETWEEN BODY WEIGHT AND RED BLOOD CELL, PLASMA AND BLOOD VOLUMES

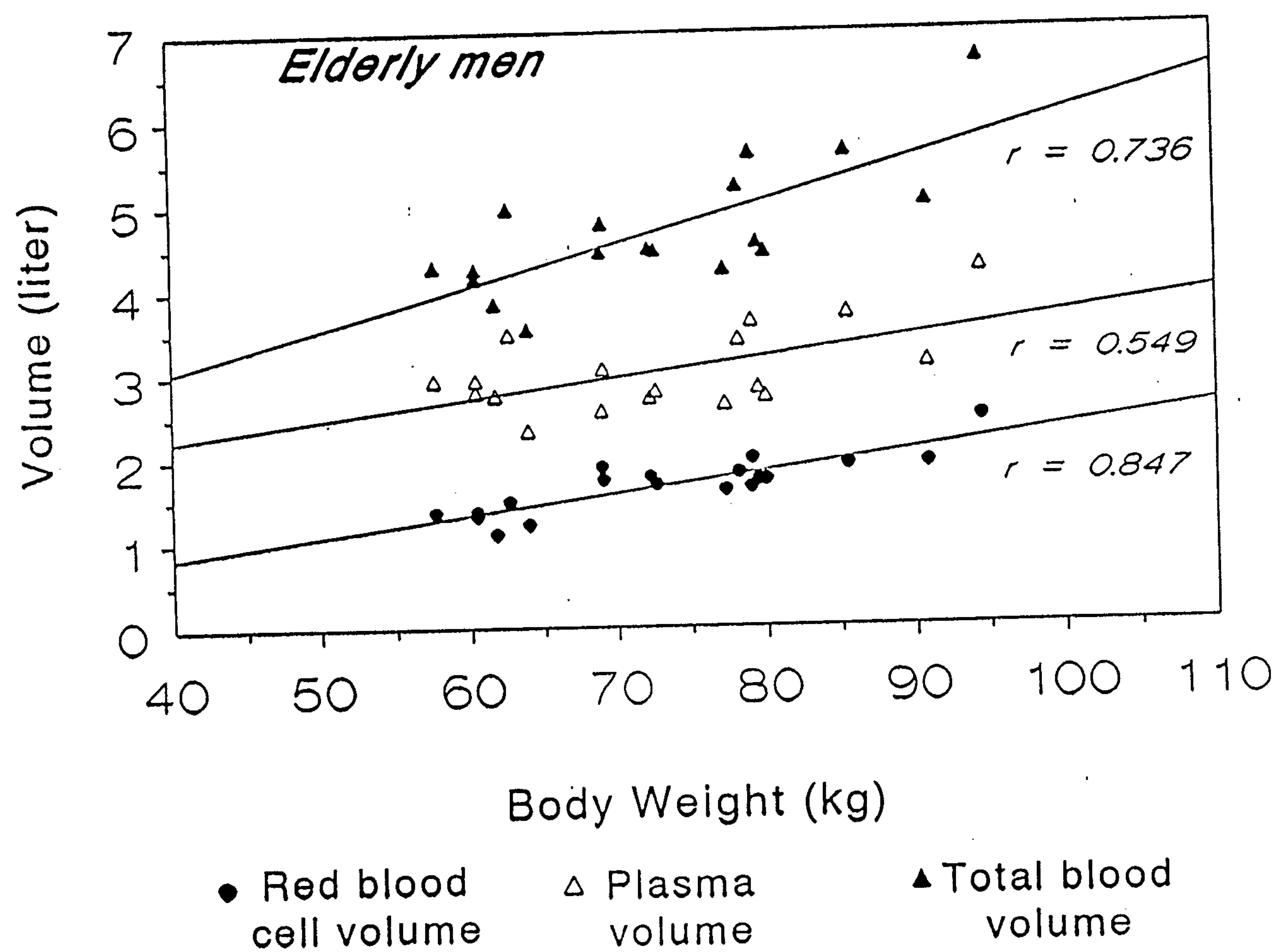

FIGURE 3

RELATIONS BETWEEN BODY SURFACE AREA (BSA) AND RED BLOOD CELL, PLASMA AND BLOOD VOLUMES IN ELDERLY WOMEN

RELATIONS BETWEEN BODY SURFACE AREA AND RED BLOOD CELL, PLASMA AND BLOOD VOLUMES

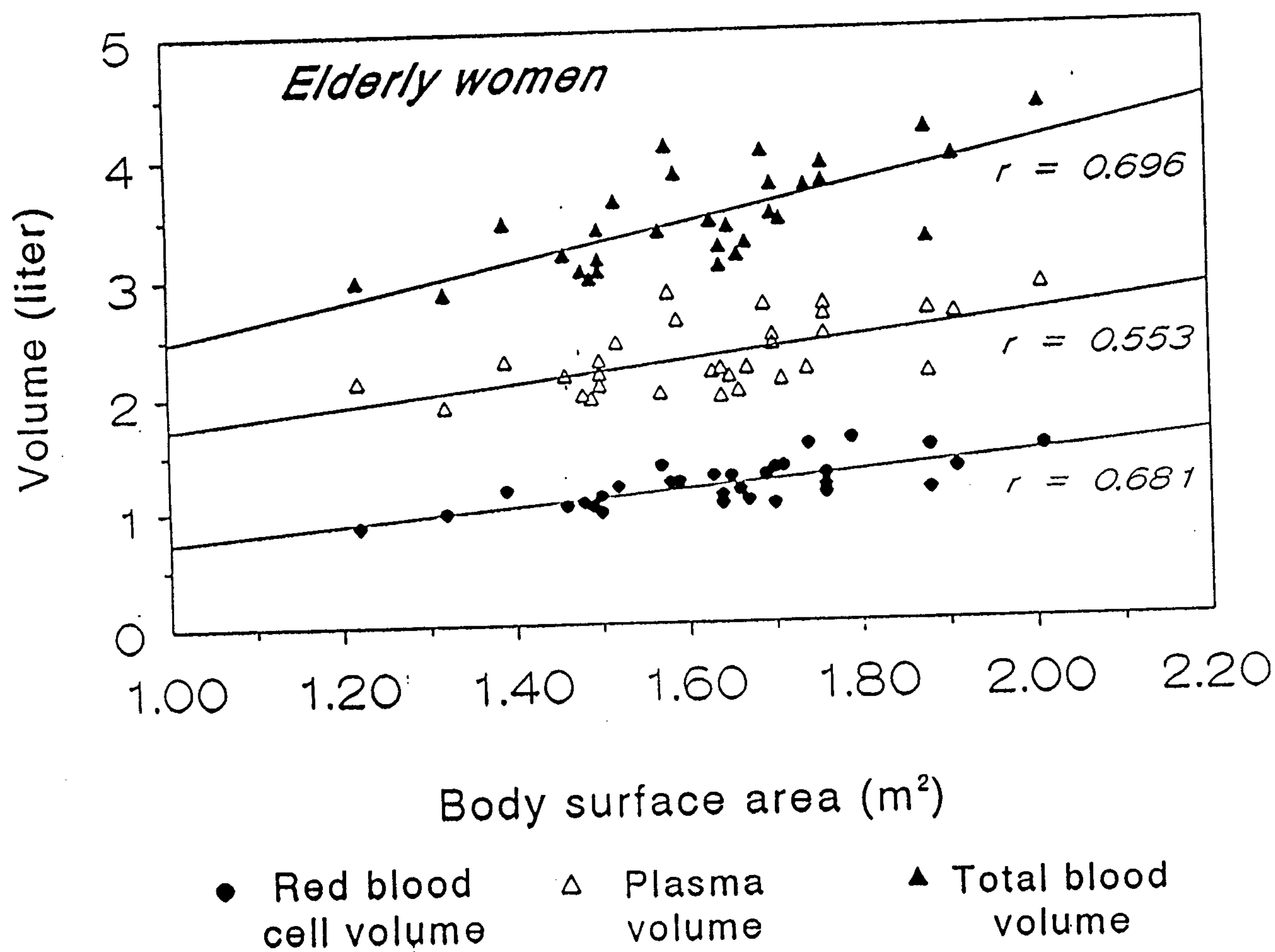

FIGURE 4

RELATIONS BETWEEN WEIGHT (WT) AND RED BLOOD CELL, PLASMA AND BLOOD VOLUMES IN ELDERLY WOMEN

RELATIONS BETWEEN BODY WEIGHT AND
RED BLOOD CELL, PLASMA AND BLOOD VOLUMES

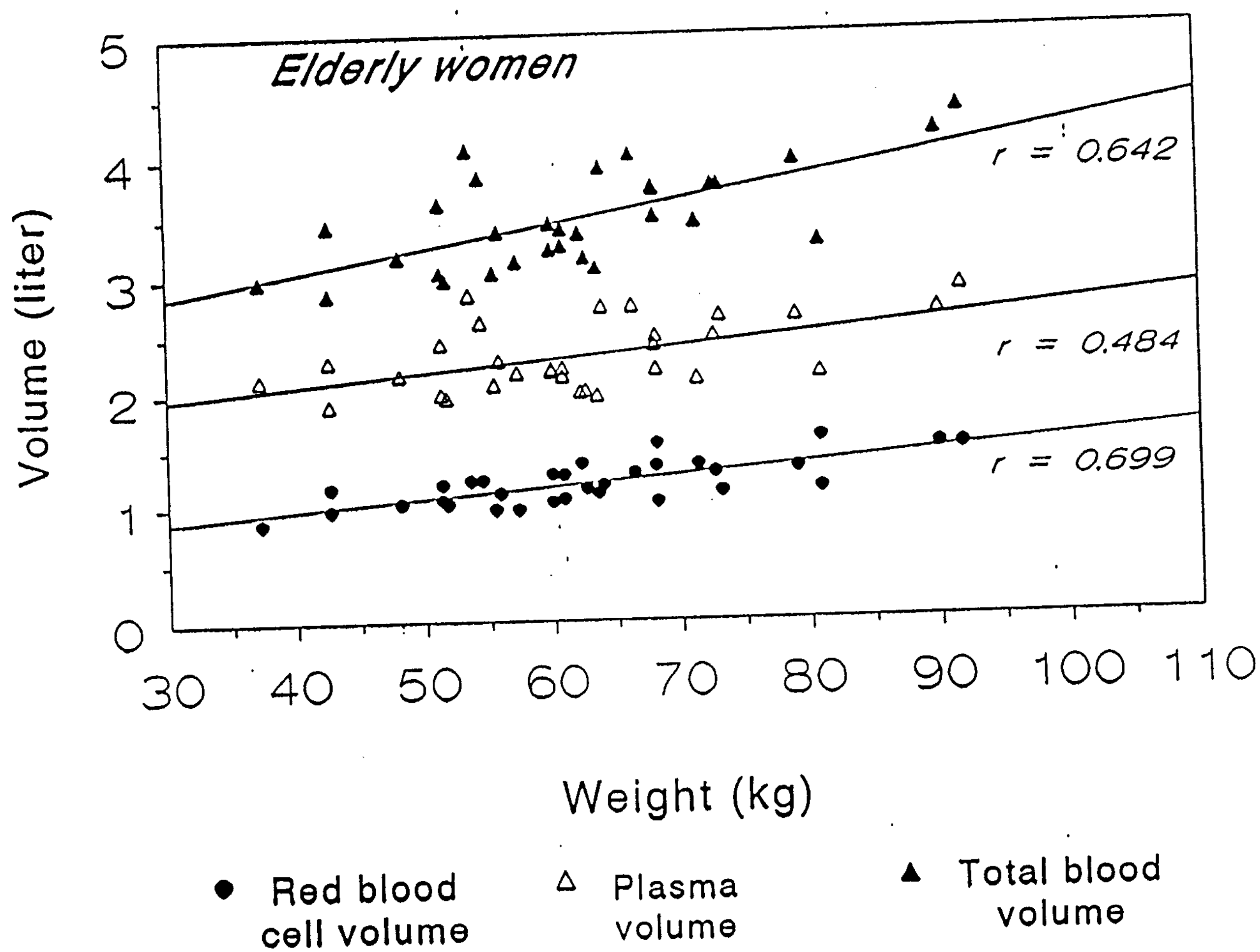

FIGURE 5

RELATIONS BETWEEN AGE AND RED BLOOD CELL 2,3 DPG, ATP, AND P50 LEVELS IN ELDERLY MEN AND WOMEN

RELATIONS BETWEEN AGE & RED BLOOD CELL 2,3DPG, ATP & P50 IN ELDERLY MEN & WOMEN

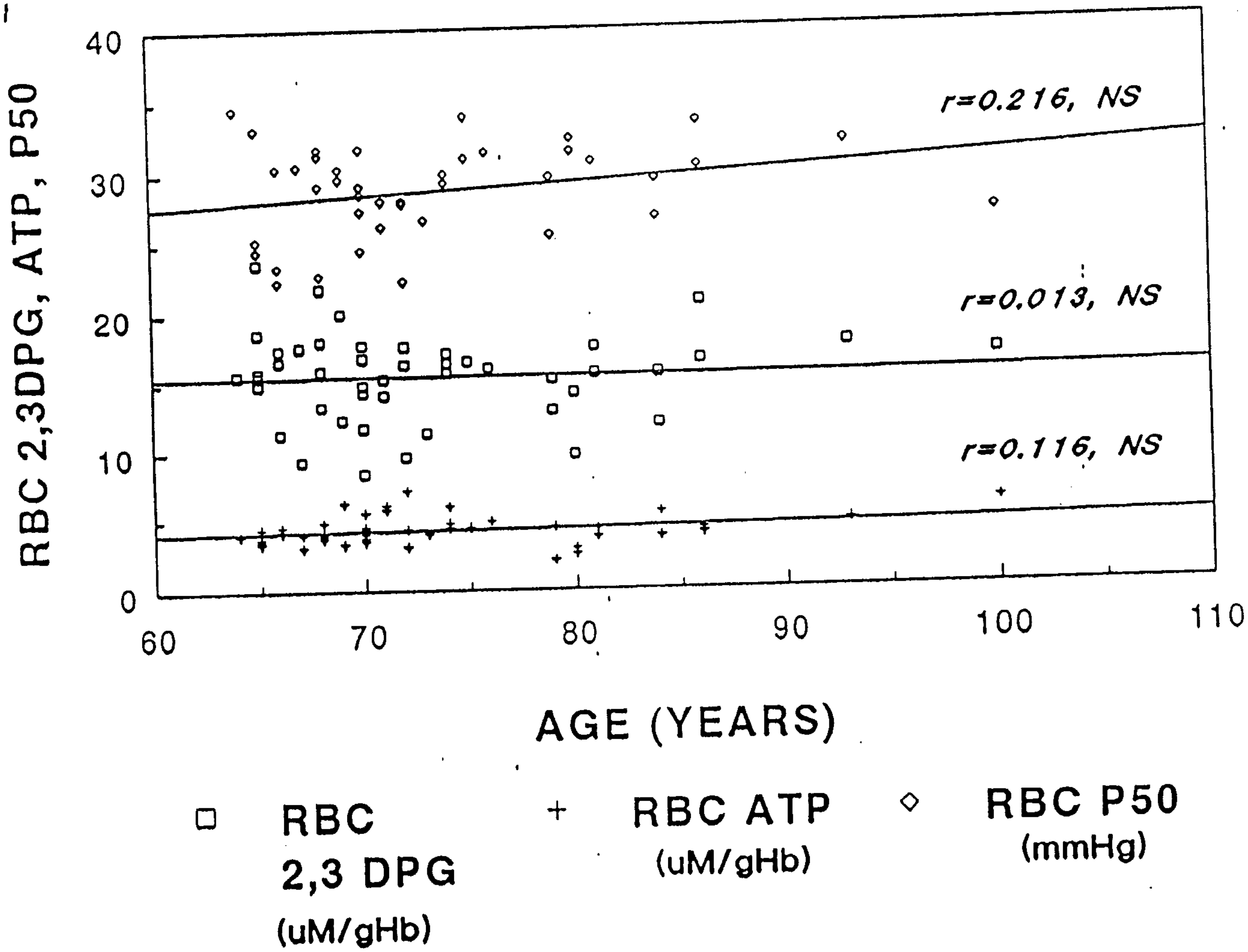

FIGURE 6

RELATION BETWEEN PERIPHERAL VENOUS HEMATOCRIT AND RED BLOOD CELL ATP LEVEL IN ELDERLY MEN AND WOMEN

RELATION BETWEEN PERIPHERAL VENOUS HCT & RED BLOOD CELL ATP IN ELDERLY MEN AND WOMEN

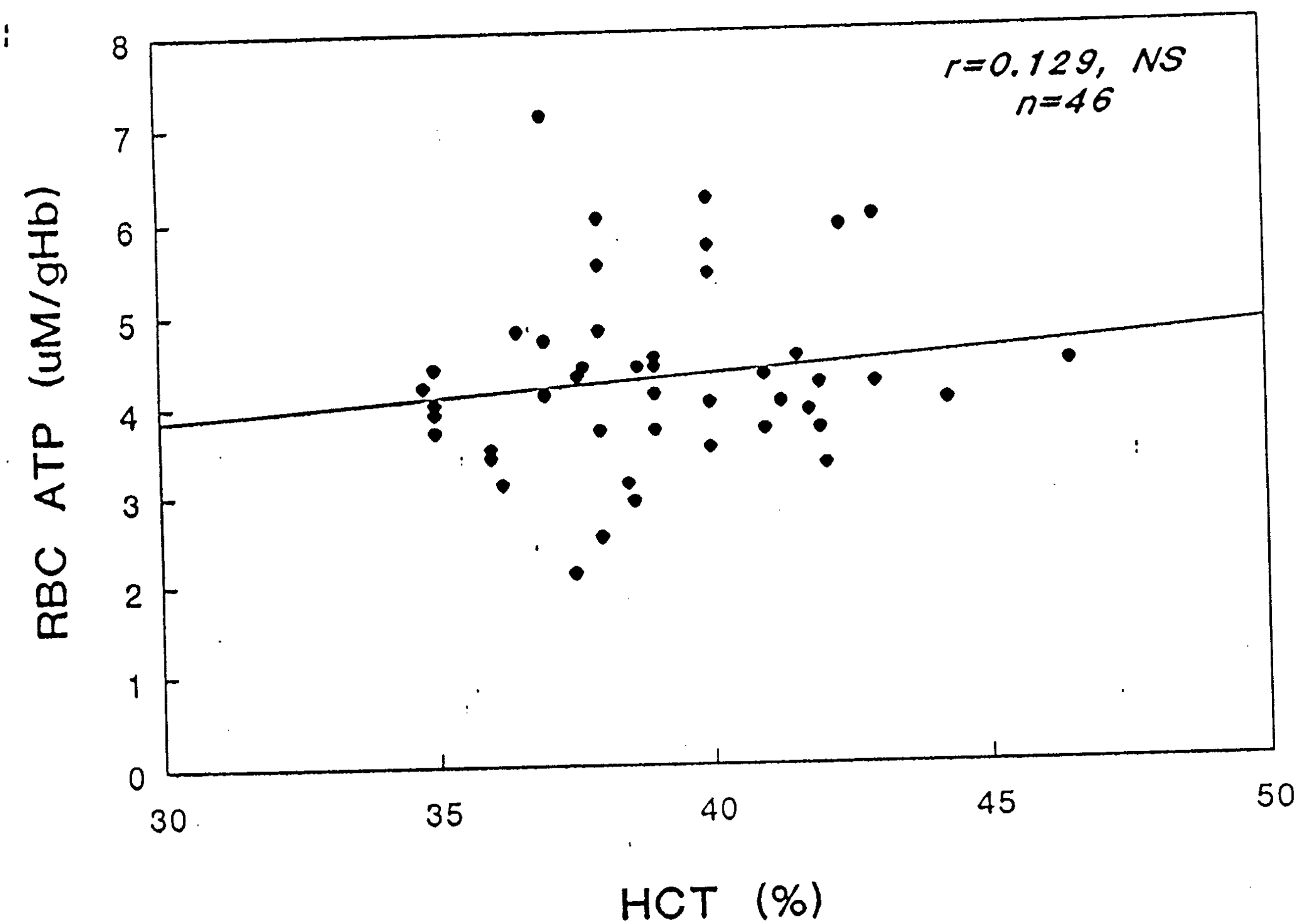

FIGURE 7

RELATION BETWEEN PERIPHERAL VENOUS HEMATOCRIT AND RED BLOOD CELL 2,3 DPG IN ELDERLY MEN AND WOMEN

RELATION BETWEEN PERIPHERAL VENOUS HCT &
RED BLOOD CELL 2,3DPG IN ELDERLY MEN AND WOMEN

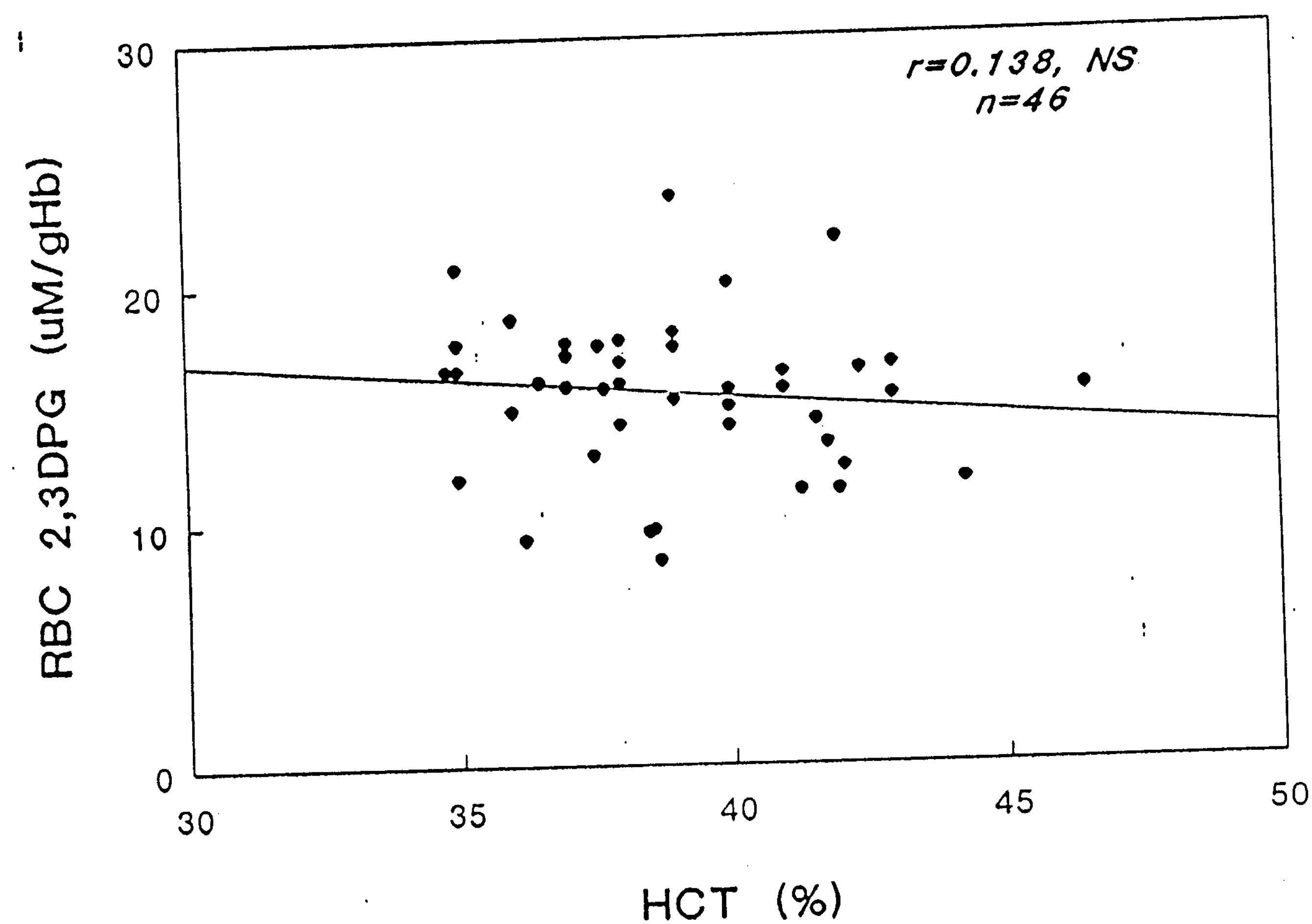

FIGURE 8

RELATION BETWEEN PERIPHERAL VENOUS HEMATOCRIT AND RED BLOOD CELL P50 IN ELDERLY MEN AND WOMEN

RELATION BETWEEN PERIPHERAL VENOUS HCT & RED BLOOD CELL P50 IN ELDERLY MEN & WOMEN

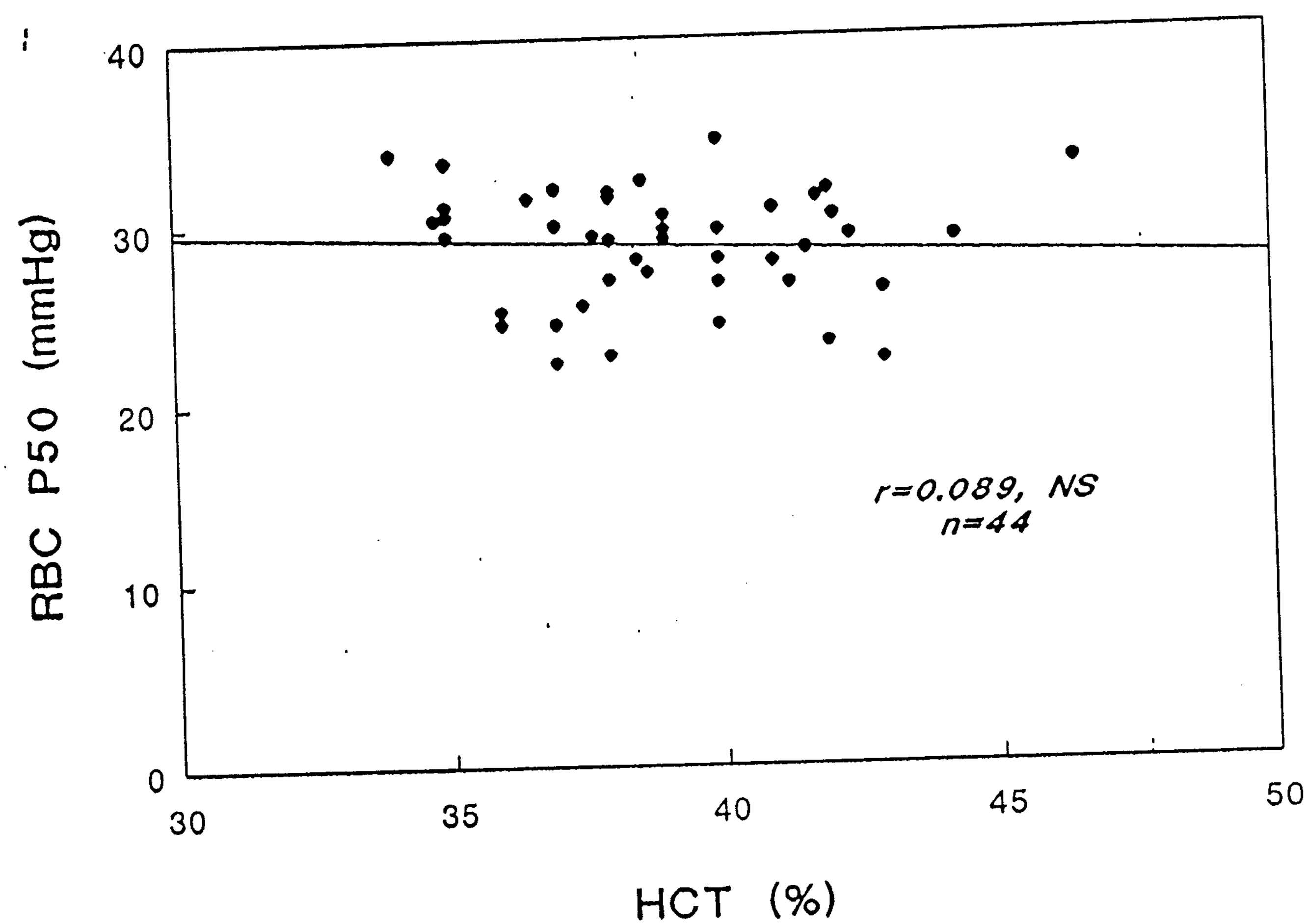

FIGURE 9

RELATION BETWEEN RED BLOOD CELL VOLUME AND RED BLOOD CELL ATP LEVELS IN ELDERLY MEN

RELATION BETWEEN RED BLOOD CELL VOLUME &
RED BLOOD CELL ATP IN ELDERLY MEN

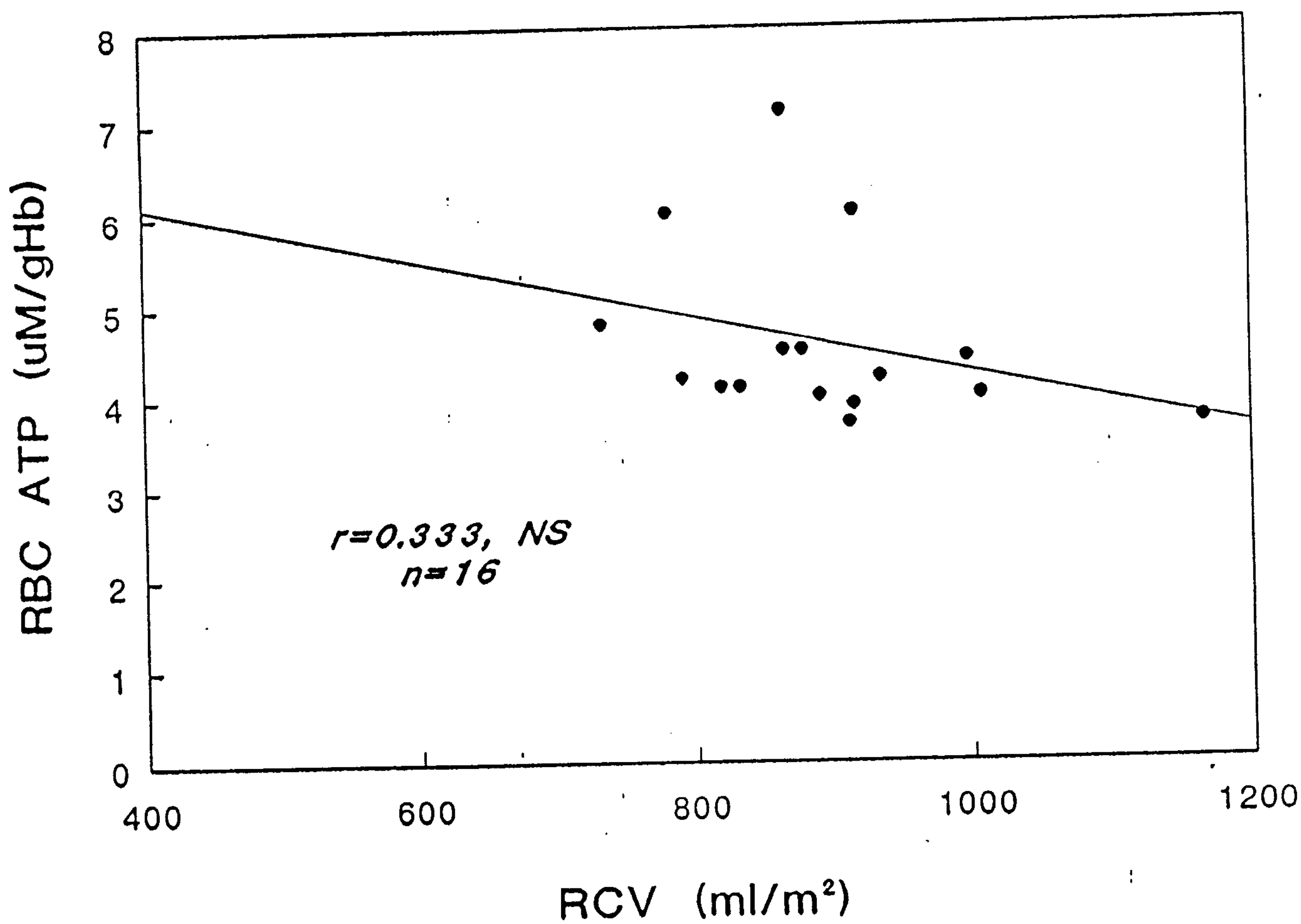

FIGURE 10

RELATION BETWEEN RED BLOOD CELL VOLUME AND RED BLOOD CELL 2,3 DPG LEVEL IN ELDERLY MEN

RELATION BETWEEN RED BLOOD CELL VOLUME & RED BLOOD CELL 2,3DPG IN ELDERLY MEN

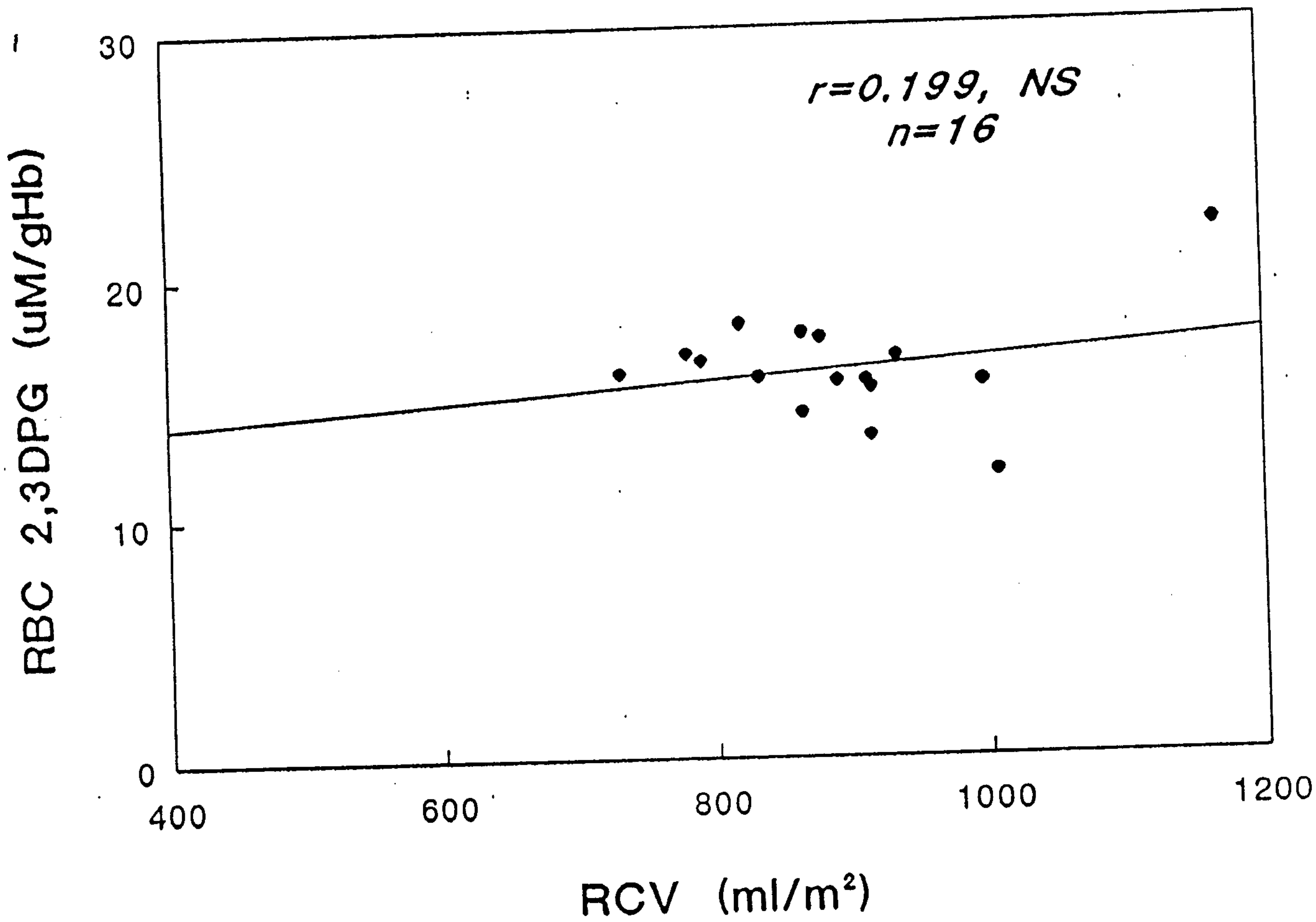

FIGURE 11

RELATION BETWEEN RED BLOOD CELL VOLUME AND RED BLOOD CELL P50 LEVELS IN ELDERLY MEN

RELATION BETWEEN RED BLOOD CELL VOLUME & RED BLOOD CELL P50 IN ELDERLY MEN

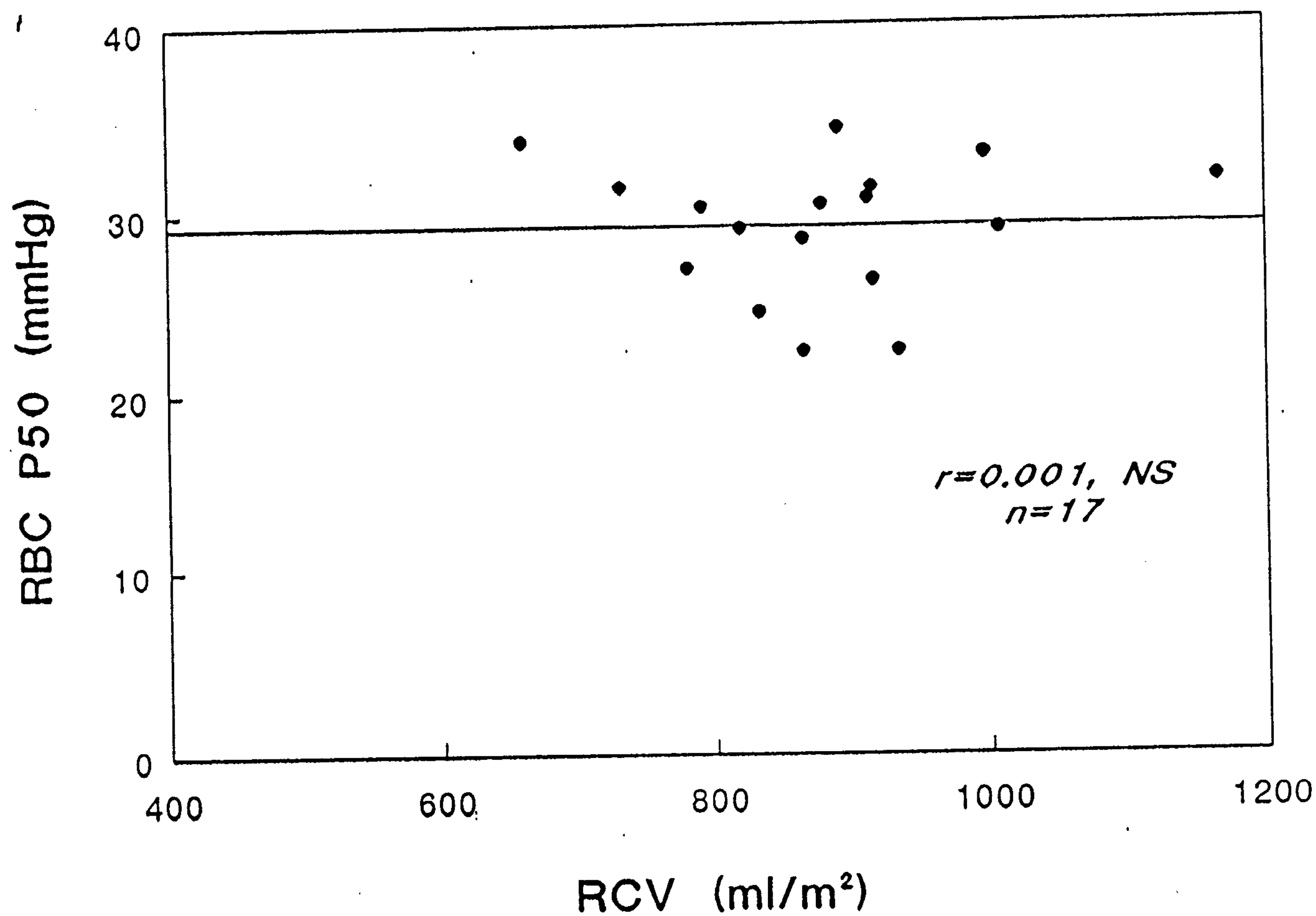

FIGURE 12

RELATION BETWEEN RED BLOOD CELL VOLUME AND RED BLOOD CELL ATP LEVELS IN ELDERLY WOMEN

RELATION BETWEEN RED BLOOD CELL VOLUME & RED BLOOD CELL ATP IN ELDERLY WOMEN

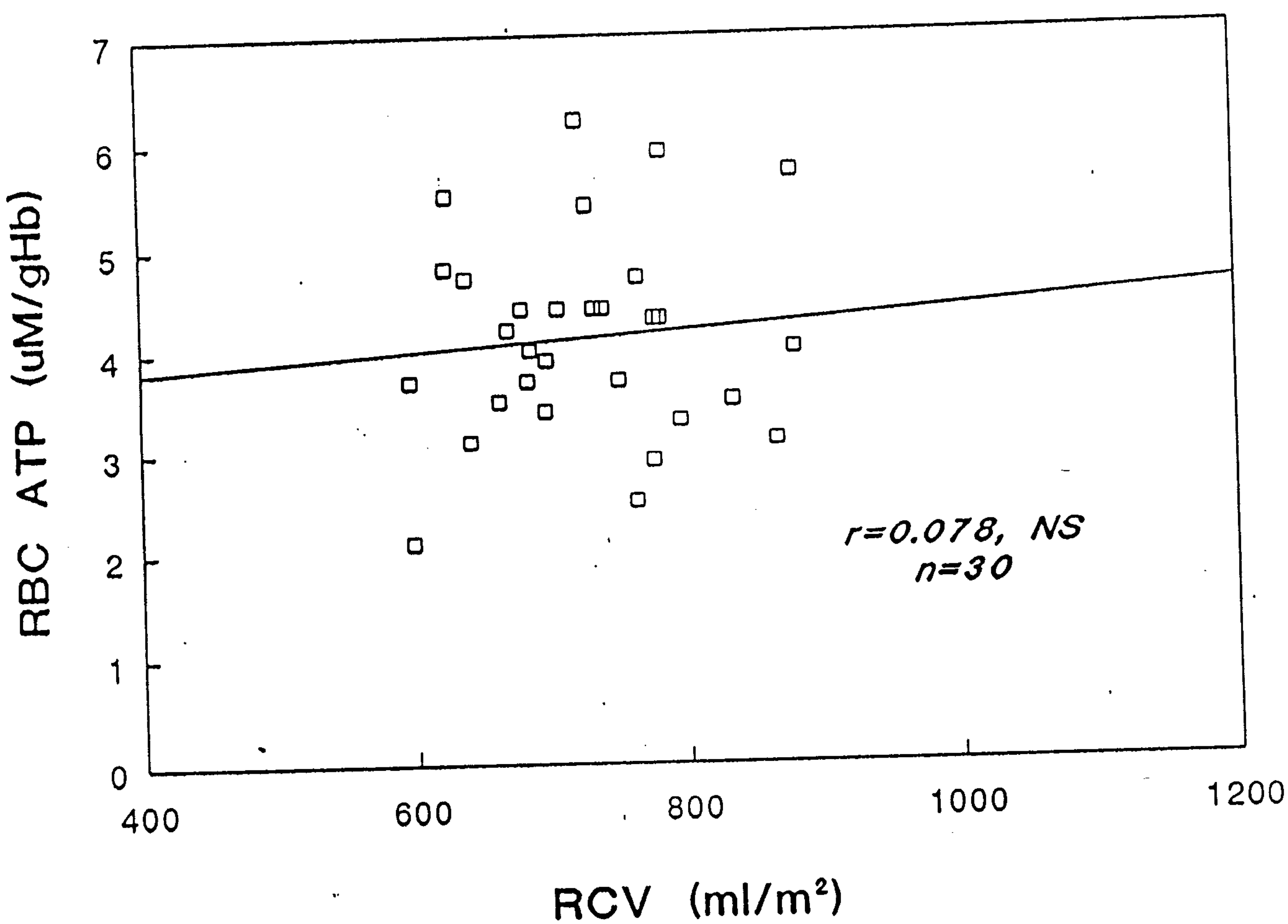

FIGURE 13

RELATION BETWEEN RED BLOOD CELL VOLUME AND RED BLOOD CELL 2,3 DPG LEVELS IN ELDERLY WOMEN

RELATION BETWEEN RED BLOOD CELL VOLUME & RED BLOOD CELL 2,3DPG IN ELDERLY WOMEN

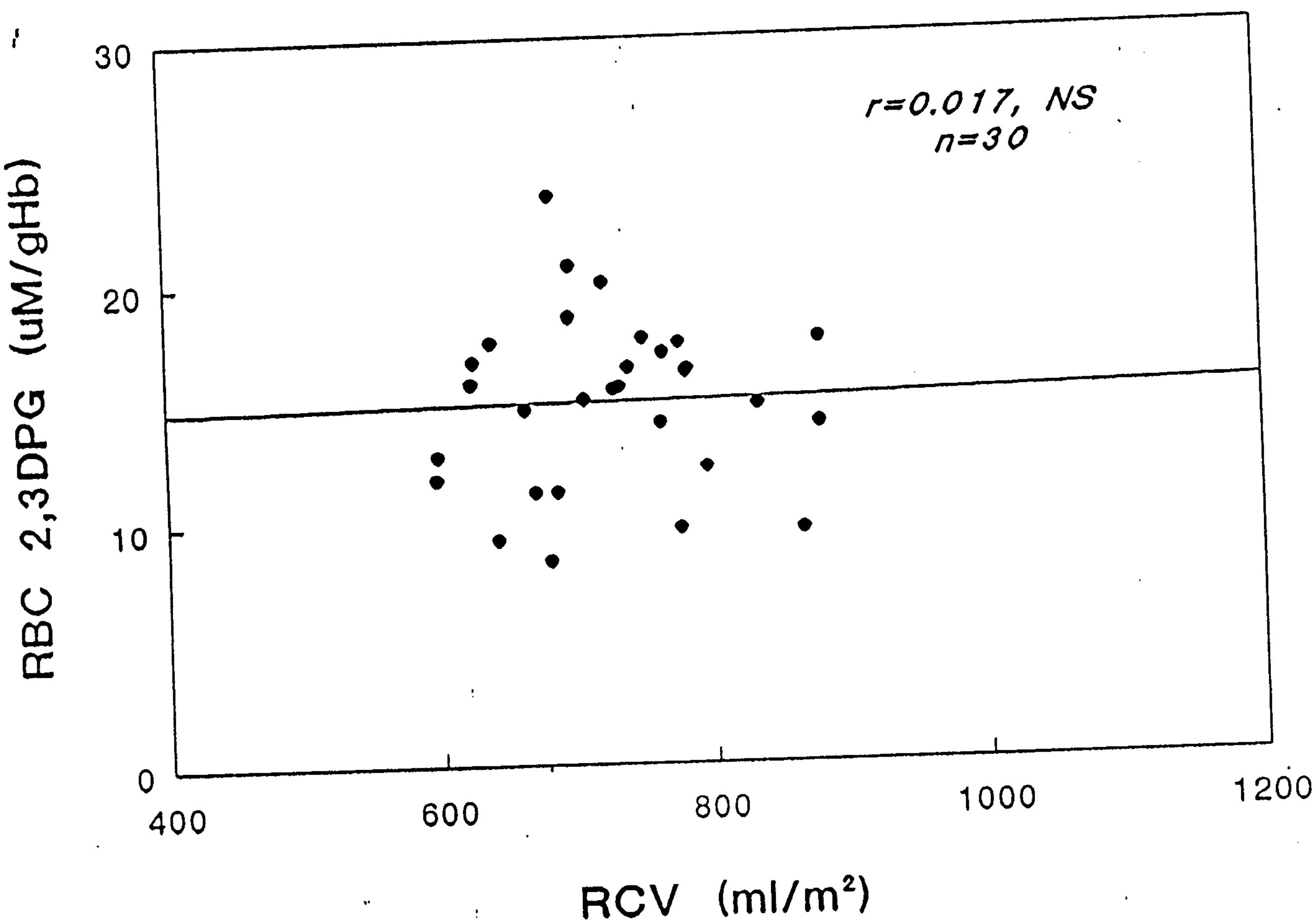

FIGURE 14

RELATION BETWEEN RED BLOOD CELL VOLUME AND RED BLOOD CELL P50 LEVELS IN ELDERLY WOMEN

RELATION BETWEEN RED BLOOD CELL VOLUME & RED BLOOD CELL P50 IN ELDERLY WOMEN

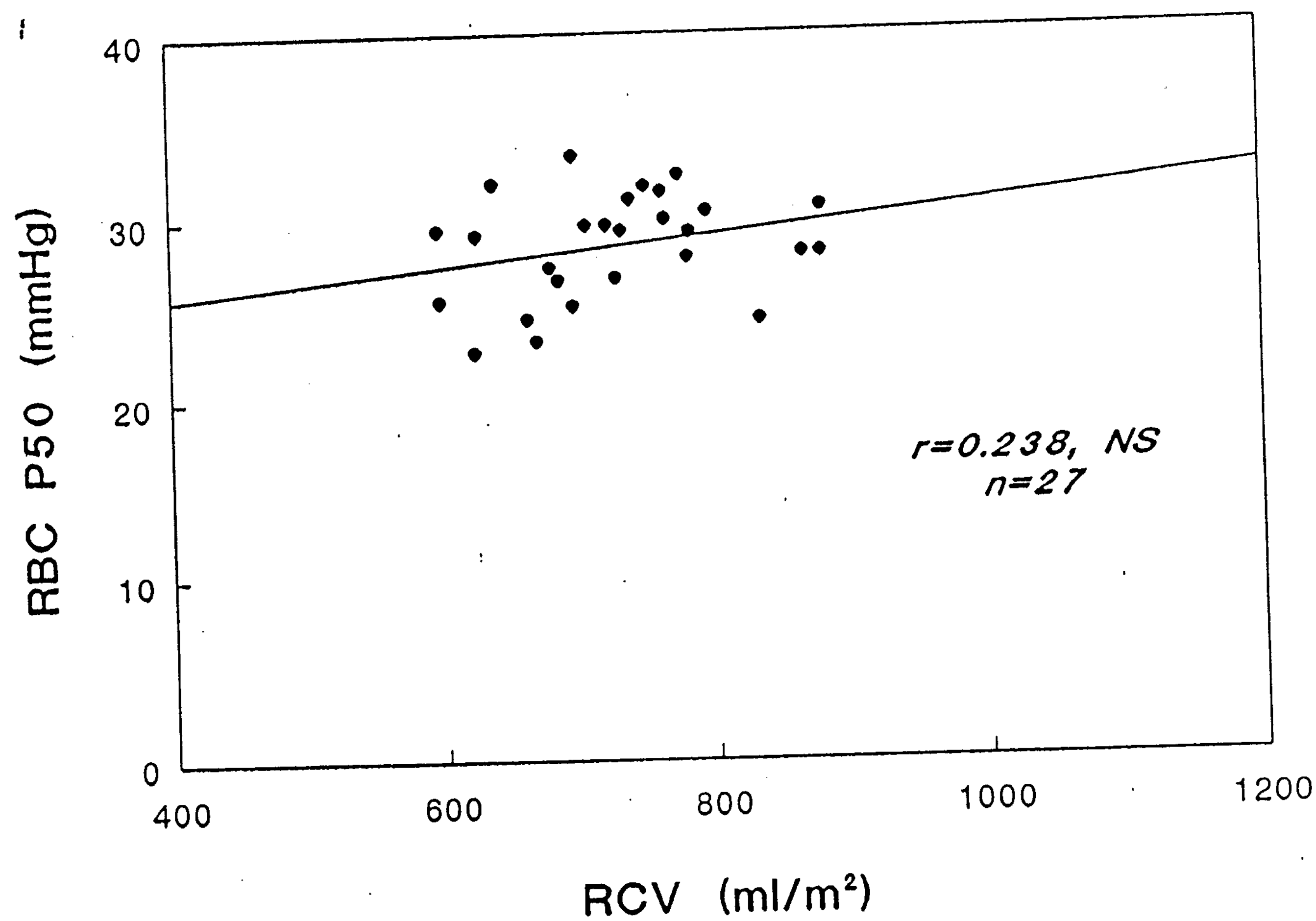

Table 1

HEALTHY ELDERLY VOLUNTEERS

	Age	Height (inches)	Weight (kg)	BSA (m2)	Peripheral Venous Hematocrit (%)
Males					
Mean:	73.4	67.5	73.4	1.86	40.0
SD:	9.2	3.4	10.9	0.16	3.4
n:	19	19	19	19	19
Minimum:	64.0	62.0	57.7	1.65	34.0
Maximum:	100.0	74.5	94.5	2.13	46.5
Females					
Mean:	73.8	62.4	62.7	1.63	38.2
SD:	6.9	2.7	13.0	0.17	2.2
n:	32	32	32	32	32
Minimum:	65.0	56.0	37.3	1.22	35.0
Maximum:	93.0	68.0	91.8	2.01	42.4

Table 2

RED BLOOD CELL VOLUMES MEASURED USING 51CR LABELED AUTOLOGOUS RED BLOOD CELLS AND PLASMA VOLUMES MEASURED USING 125I ALBUMIN IN HEALTHY ELDERLY VOLUNTEERS

		Males	Females
51Cr Red Blood Cell Volume (ml)	Mean:	1662	1185
	SD:	325	181
	n:	19	32
125I Albumin Plasma Volume (ml)	Mean:	3029	2310
	SD:	480	289
	n:	18	31
Total Blood Volume (ml)	Mean:	4693	3482
	SD:	757	395
	n:	18	31
51Cr Red Blood Cell Volume (ml/M2 BSA)	Mean:	889	725
	SD:	114	79
	n:	10	32
125I Plasma Volume (ml/M2 BSA)	Mean:	1634	1424
	SD:	201	161
	n:	18	31
Total Blood Volume (ml/M2 BSA)	Mean:	2626	2144
	SD:	251	186
	n:	18	31
51Cr Red Blood Cell Volume (ml/kg)	Mean:	22.6	19.3
	SD:	2.4	2.9
	n:	19	32
125 I Albumin Plasma Volume (ml/kg)	Mean:	41.9	38.3
	SD:	6.5	7.5
	n:	18	31
Total Blood Volume (ml/kg)	Mean:	64.6	57.6
	SD:	7.4	9.8
	n:	18	31
Total Body Hematocrit (%)	Mean:	35.4	33.5
	SD:	3.7	3.2
	n:	18	32
F Value	Mean:	0.88	0.88
	SD:	0.05	0.06
	n:	18	32

TABLE 3

REGRESSION EQUATIONS RELATING RED BLOOD CELL, PLASMA AND TOTAL BLOOD VOLUMES TO BODY SURFACE AREA AND BODY WEIGHT IN THE ELDERLY MEN AND WOMEN

	Men	Women
Red Blood Cell Volume, ml	= 1761 (m^2) - 1608	716 (m^2) + 14
	25.1 (kg) - 183	9.7 (kg) + 573
Plasma Volume, ml	= 1995 (m^2) - 667	925 (m^2) + 802
	24.3 (kg) + 1255	10.9 (kg) + 1630
Total Blood Volume, ml	= 3809 (m^2) - 2362	1591 (m^2) + 889
	49.9 (kg) + 1044	19.9 (kg) + 2247

Table 4

RED BLOOD CELL, PLASMA AND TOTAL BLOOD VOLUME IN YOUNG AND ELDERLY MEN AND WOMEN

			MEN						WOMEN					
	Age of	Method	ml/m2 Surface Area			ml/kg Body Weight			ml/m2 Surface Area			ml/kg Body Weight		
Study	Subject	RCV/PV	RCV	PV	TBV	RCV	PV	TBV	RCV	PV	TBV	RCV	PV	TBV
Sawka et al 7	18-35	51Cr 125I Alb	1000	1685	2685	26	43	69	-	-	-	-	-	-
Wennesland et al 4	19-52	51Cr -	1089	-	-	27	-	-	-	-	-	-	-	-
Huff & Feller 3	16-66	51Cr -	-	-	-	28	-	-	-	-	-	24	-	-
Retzlaff et al 5	20-66	51Cr T-1824	1095	1631	2726	27	40	67	834	1399	2233	23	39	62
Piomelli et al 10	18-29	51Cr	-	-	-	30		68						
Schmidt et al 8	70-94	- T-1824	-	1610	-	-	-	-	-	1480	-	-	-	-
Sklaroff 9	60-99	- 131I Alb	-	-	-	-	37	-	-	-	-	-	32	-
Piomelli et al 10	75-92	51Cr	-	-	-	26	-	57						
Present Study	64-100	51Cr 125I Alb	889	1634	2626	23	42	65	725	1424	2144	19	38	58

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